Distributed Environment Monitoring

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

By

Debasish Shanti (Electronics & Communication Engineering)

Pratik Das (Electronics & Instrumentation Engineering)

Department of Electronics and Communication Engineering
National Institute of Technology
Rourkela
Orissa

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CERTIFICATE

This is to certify that the work in this thesis entitled ***"Distributed Environment Monitoring"*** by ***Debasish Shanti and Pratik Das***, has been carried out under my supervision in partial fulfillment of the requirements for the degree of Bachelor of Technology in **'Electronics and Instrumentation Engineering'** during the session 2010 – 2014 in the Department of Electronics and Communication Engineering, National Institute of Technology, Rourkela and this work has not been submitted elsewhere for a degree.

Place :
Date :

Prof. U. K. Sahoo
Professor, Dept. of ECE
National Institute of Technology, Rourkela

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Debasish Shanti Pratik Das

ABSTARCT

The Wireless Sensor Networks have gained tremendous popularity due to the vast potential of the sensor networks to interconnect the physical world with the virtual world. Since these devices depend on battery power and may be placed in harsh and inaccessible environments replacing them is a very difficult task. Thus, improving the energy of these networks is a very important task.

The thesis provides methods for clustering and cluster head selection to WSN to improve energy efficiency. It presents a comparison between the different methods on the basis of the network lifetime. It proposes a modified approach for cluster head selection with good performance and reduced computational complexity .In addition it also proposes a modified version of Dijkstra's algorithm for data routing and Minimum Volume Enclosing Ellipsoid for data representation to reduce amount of data.

ABBREVIATIONS

BS	Base Station
CH	Cluster Head
LCA	Linked Cluster Algorithm
MVEE	Minimum Volume Ellipsoid
RCC	Random Competition Based Clustering
WSN	Wireless Sensor Network

CONTENTS

Chapter-1
INTRODUCTION

1.1 Wireless Sensor Networks

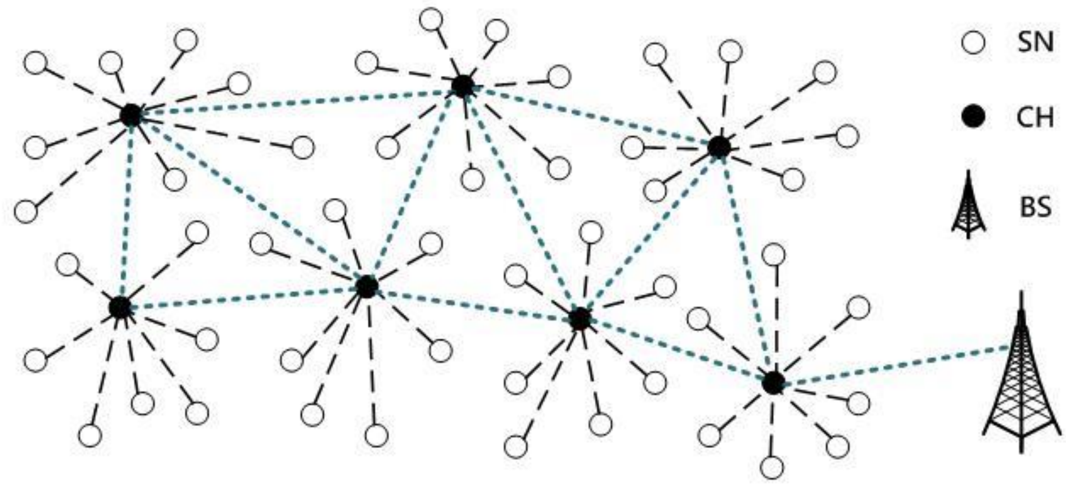


Fig. 1

Wireless sensor networks have become a field for intensive research during recent years. The reason being as it acts as a bridge between the physical world and the virtual world it has unlimited potential applications in the contemporary world. Interconnecting a large number of sensors allows us to observe physical environment at a much finer detail which was not possible before. Development in manufacturing process has scaled down the sensor nodes size and cost boosting the use of large-scale wireless sensor networks whose applications include:

Military applications like command, control, communications, surveillance, targeting, battle damage assessment, nuclear and biological attack detection etc.

Environmental applications like forest fire detection, bio-complexity mapping of environment, flood detection precision agriculture etc.

Health applications like tele-monitoring of human physiological data, tracking and monitoring of patients inside a hospital, drug administration etc.

Home applications like home automation, smart environment etc.

All these applications have some minimum requirements like minimum coverage area, maximum allowed chance of false alert etc. The sensor network should provide these minimum requirements for a long time using limited resources without any outside interference. Meeting these goals requires careful design of hardware and intensive optimization of different methods and protocols used.

The most important aspect of a sensor node is its power usage. Wireless transmission requires huge amount of power and if not taken care of may lead to an early failure of the network. This is done by minimization of transmission distance and minimization of data to be transmitted.

Minimization of distance

Transmission power its directly proportional to the signal strength which depends on the distance of transmission. If all nodes were to communicate with the control center directly the battery of distant nodes will die very quickly causing the network to fail. This is avoided to a certain extent via clustering. In clusters, nodes report to the cluster head reducing their transmission distance. Multi-hop communication is used between cluster heads decrease their transmission distance.

Minimization of data

In a node wireless transmission consumes highest amount of power. So it is more practical to do some on-board processing to minimize transmission than to transmit raw data continuously. This is done by programming acceptable values of physical variables. So the sensors transmit only when the environment deviates from acceptable range.

When a phenomenon occurs multiple sensors may sense it and transmit. To avoid this clustering is used. But even if the cluster head is the only one transmitting, total data from all the sensors is huge. So data representation techniques are used to minimize data to be transmitted.

Chapter-2
CLUSTERING

2.1 Introduction

To minimize transmission by sensor nodes, clustering is used in which a group of nodes transmit a single message. Clustering involves cluster head election and then cluster formation.

2.2 Some Clustering Algorithms

Some clustering algorithms are mentioned below:

2.2.1 <u>Linked Cluster Algorithm:</u>

In LCA the cell concept of mobile phone service is used.

Here for every few nodes a dedicated leader node with higher capabilities and power is deployed. The dedicated node collects the data from nodes whenever required and transmit it.

After deployment of the leader node, it transmits a message inviting nodes to join it to form a cluster. The nodes then join the leader node from whom they receive maximum signal strength. After joining, the nodes transmit their ID to the leader. The leader then assigns time slots to the nodes for transmission according to their ID.

2.2.2 Adaptive Clustering:

This employs an ID based clustering scheme. A single-hop intra-cluster topology is established in this clustering i.e. each node in the cluster can communicate with each other in a single hop. After cluster formation, the node with the lowest ID becomes the CH. Distinct codes are assigned to each cluster for communication. A CH arbitrates selection of communication codes with the neighboring CHs.

The algorithm tries to optimize the cluster size by balancing the interests in spatial reuse of channels by having small clusters, data delivery delay etc.

2.2.3 Random Competition Based Clustering:

Although designed for mobile ad-hoc networks, it is also applicable to WSNs. It applied the rule 'first declaration wins', in which any node can become the CH, provided it first claims to be the CH. After hearing the claim, neighboring nodes join the cluster as members and give up the right to become a CH. To maintain the network every CH in the network broadcast a CH packet periodically.

To avoid concurrent lines by multiple neighboring nodes, RCC employees random timer and uses to node ID arbitration. Each node in the network resets its timer value before broadcasting the CH claim packet. During this random time, if it gets a CH claim packet from another node, simply ceases its broadcast of CH claim packet. Since this is not a complete solution, this is for the resolved by using node ID. If conflict persists, node having lower ID becomes the CH.

2.3 Energy Efficient Clustering

The clustering algorithms mentioned before prolong network lifetime, but the CHs are selected randomly. This may lead to an early failure of the network if the heads selected have low power instead of nodes having high power.

To extend the lifetime of a WSN even more, Energy Efficient Clustering is used. This its dome by local communication between nodes and selecting the node with the highest residual energy as the CH. The cluster load is balanced between CHs to further decrease the power usage. This technique can prolong network lifetime by 135%.

This technique primarily consists of the phases: cluster head election, cluster formation, synchronization.

2.3.1 Assumptions:

1. N sensors are uniformly dispersed in a square field.

2. All sensors and BS are stationary after deployment.

3. The communication is based on single hop.

4. Communication is symmetric and a sensor can compute the approximate distance based on received signal strength.

5. All sensors are aware of their location.

6. All sensors are of equal significance.

7. Once any node runs out of energy, the WSN is considered dead because some area cannot be monitored.

2.3.2 Cluster Head Selection:

In this phase, several heads are selected. The nodes become candidate nodes with some probability. Then the product cast a message with in radio range to show that they are competing to be a CH. Each candidate node checks whether there is another candidate node with more residual energy within its radius. If such a node it's found then the node gives up the competition. Otherwise, it is selected as the head in the end.

2.3.3 Cluster Formation:

In this phase, each CH broadcasts a head message across the network, while all other nodes receive the message and decide which cluster to join. The nodes join the head with the highest signal strength.

2.3.4 Synchronization:

Synchronization between each phase is a must. Otherwise some notes will not have enough time to complete the procedure. Synchronization within a phase is not required. The idle nodes will turn to sleep till the phase ends. This can be achieved by having the BS periodically broadcast synchronization signals to all nodes.

Chapter-3
MULTI-HOP COMMUNICATION

3.1 Introduction

In a WSN direct communication of the cluster heads with the BS is avoided as the distance is very high which would use up a lot of battery power. So multi-hop communication is adopted in WSNs. To ensure minimal use of battery power, shortest path algorithms are used which ensure that the distance travelled by the data in a multi hop communication structure is minimum.

3.2 Some Shortest Path Algorithms

Among all existing algorithms the note-worthy are:

- Dijkstra's algorithm

- A* algorithm

3.2.1 Dijkstra's Algorithm:

Let node at which we are starting the called the initial node. Let distance of node y be the distance of initial node to node y.

Steps:

1. Every node is assigned an initial distance value: zero for initial node and infinity for others.

2. All the unvisited nodes are marked. The initial node is set as current node. A set of unvisited nodes is created called the unvisited set.

3. For the current node, all of its unvisited nodes are considered and their tentative distance its calculated. The newly calculated distance and the assigned value is compared and the smaller value is assigned.

4. When consideration of all unvisited nodes is done, the current node is marked as visited and removed from the unvisited set.

5. The algorithm is stopped if the destination node is marked visited.

6. The node marked with the smallest tentative distance is selected as the new ' current node' and the algorithm is repeated from step 3.

3.2.2 A* Algorithm:

In this algorithm, the routes that appear most likely leading towards the goal, taking the distance already covered into consideration, are found out.

A priority queue of nodes to be visited is maintained known as the open set or fringe, starting with the initial node. The lower value of cost function (distance traveled + estimated distance to goal from the present position), higher is its priority. The node with the lowest cost is removed from the queue in each step of the algorithm and the cost value of the neighbors are updated accordingly. When the destination node is removed from the queue, the algorithm terminates.

3.3 Our Modification of Dijkstra's Algorithm

Dijkstra's algorithm may be ideal for implementation on cloud services and ad-hoc communication networks.

But it has a serious shortcoming in case of WSNs. Dijkstra's algorithm concentrates only on the path cost and not on the number hops. If there are too many hops the energy of many nodes will decrease simultaneously which may give rise to undesired results. So careful optimization of both distance of communication and number of hops is required.

So we adopted a slight variation of the Dijkstra's algorithm. A maximum distance of communication is set and the first path found was taken as the data communication path, i.e. the path with least number of hops is selected.

Also this algorithm cannot be implemented directly on nodes to dynamically calculate the path of data flow as the sensors are not aware of the position of other nodes. So a reference distribution is taken and the path found from this distribution is programmed into the sensors as the data path.

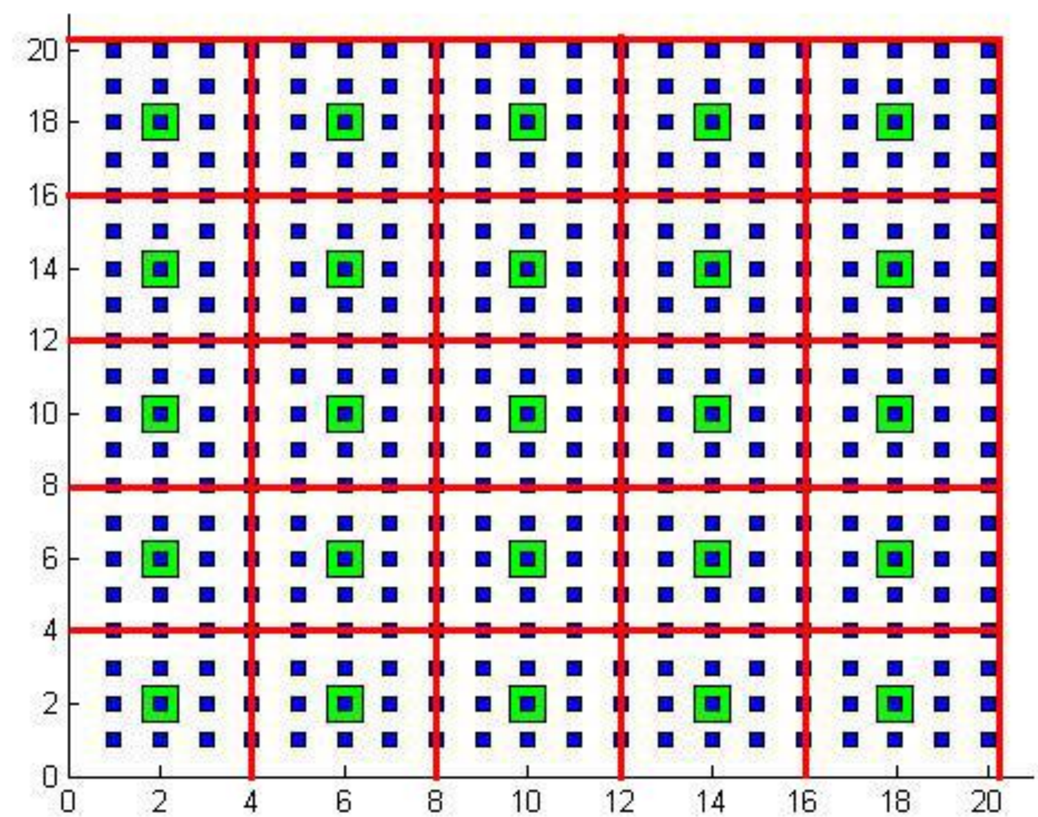
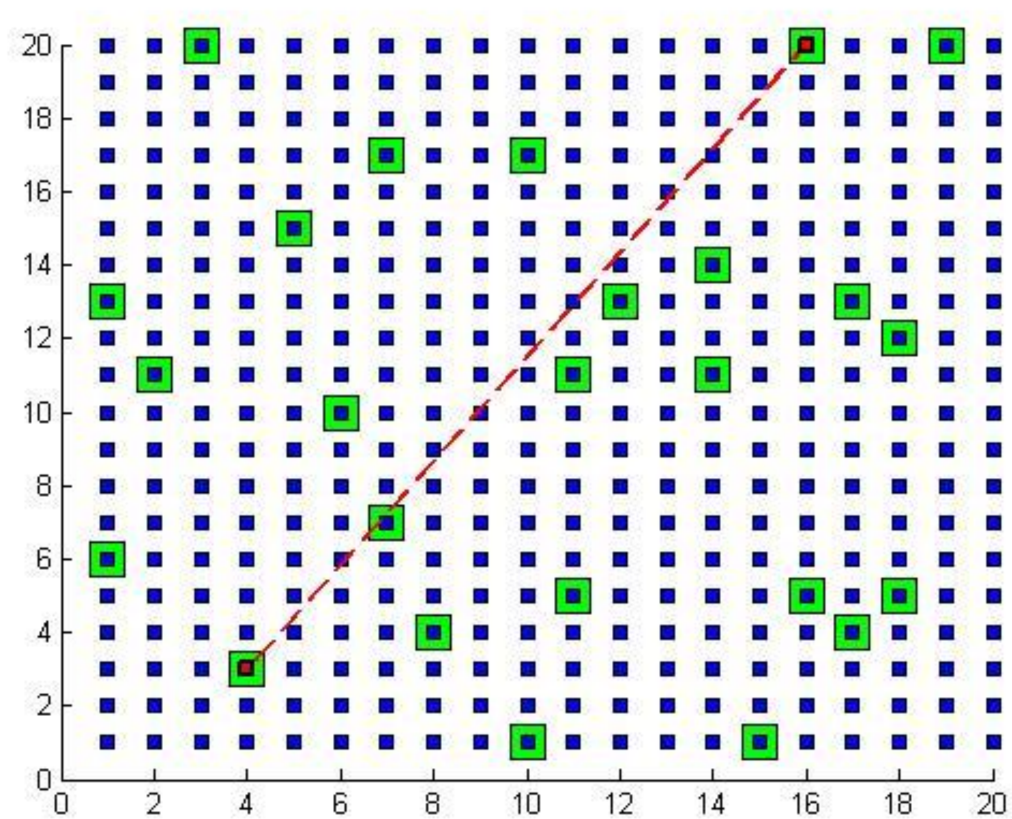


Fig. 3.1

Here the smaller dots indicate the sensor nodes. The larger dots indicate CHs. The lines are used to indicate the sectors used to select the CHs. In the algorithm the given area has been divided into 25 sectors giving rise to 25 heads.

This distribution has been used calculate the data path during simulation.

But all these modifications have to be carried out carefully so as not to generate any erroneous results. Each sensor node is assigned a maximum transmission radius. If the radius is too large, battery drain will be very high. If it is too low, the algorithm will not be able to find a path as some nosed will not be connected to any other nodes. So the algorithm will return the data path as a direct one as shown below:



To avoid these kinds of errors the maximum radius of transmission was calculated as follows:

Let the length of each sector be x.

Then the maximum distance between 2 CHs of adjacent sectors = $\sqrt{(2 * x)^2 + x^2} = \sqrt{5}x$

So the Maximum radius of transmission was chosen to be 75% of that i.e.

$$R = 0.75 * \sqrt{5}x$$

$$\text{OR,}\quad R = 1.677\, x$$

This value along with the reference distribution was used to get data path for the network.

Chapter-4
DATA OPTIMIZATION

4.1 Introduction

Even after optimizing all other aspects, the network lifetime doesn't improve much is the data to be transmitted is not optimized.

Usually in the WSNs, anomalies in physical variables are transmitted, i.e. when the environment goes beyond the acceptable range. When an anomaly occurs, a lot of sensors catch the anomaly. So if all the data is to be transmitted, it would give rise to a huge amount of data which will consume considerable amount of power.

To decrease the amount of data usually a few parameters are calculated which would indicate the area where the anomaly has occurred and has to be checked. This is done by the cluster head. The sensors normally send data to their respective heads. The heads approximately calculate the area to be checked using various algorithms.

4.2 Some Data Representation Algorithms:

4.2.1 Enclosing Rectangle:

This is the simplest algorithm for approximating the area. The smallest and the largest x, y coordinates are found out among the sensors that report the anomaly. Then these 4 coordinated are sent to the BS forming a rectangle.

4.2.2 Minimum Volume Enclosing Ellipsoid (MVEE):

Even though the enclosing rectangle algorithm is very simple, it's error percentage is very high as the sensors reporting the anomaly actually occupy very less area than that indicated by the algorithm.

So usually nonlinear optimization techniques are used. Minimum volume ellipsoid is one of them. This is used to calculate the bounding ellipse of all points in a 2-D plane or bounding ellipsoid in a 3-D space.

Let P be the matrix containing all the data points, A be the output matrix containing the equation of ellipse in center form and C be the center of the ellipse.

The minimum volume ellipsoid is calculated by minimizing log(det(A)), subject to the condition:

$$(p(i)(:) - C)' * A * (p(i)(:) - C) <= 1$$

Where P(i)(:) denotes the i^{th} row of matrix P.

Chapter-5
SIMULATION RESULTS

5.1 Simulation results for Energy Efficient Clustering:

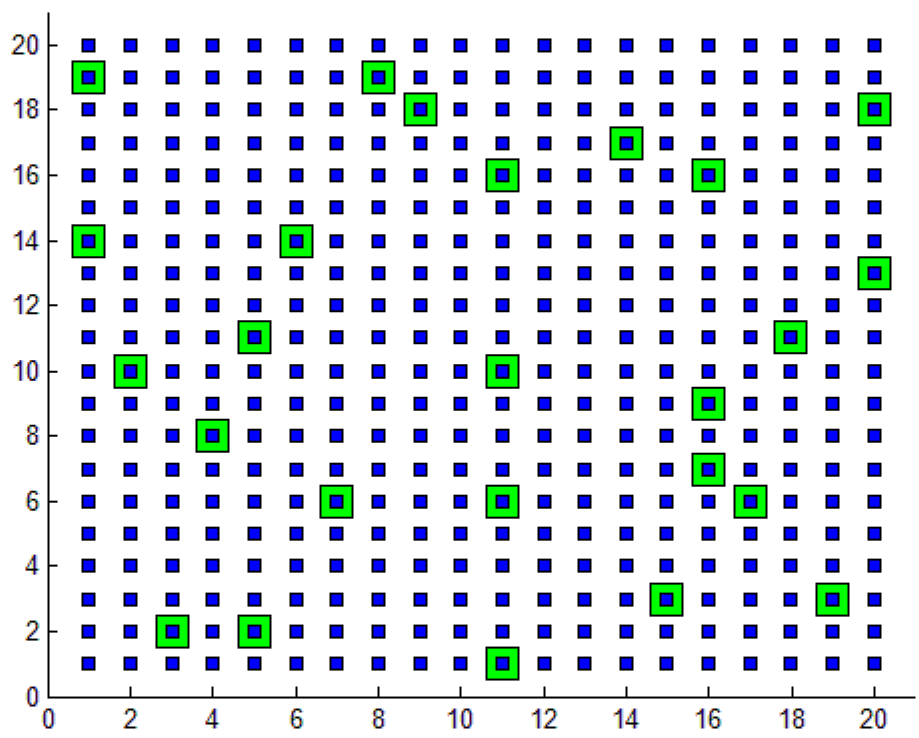


Fig 5.1 – Stage 1

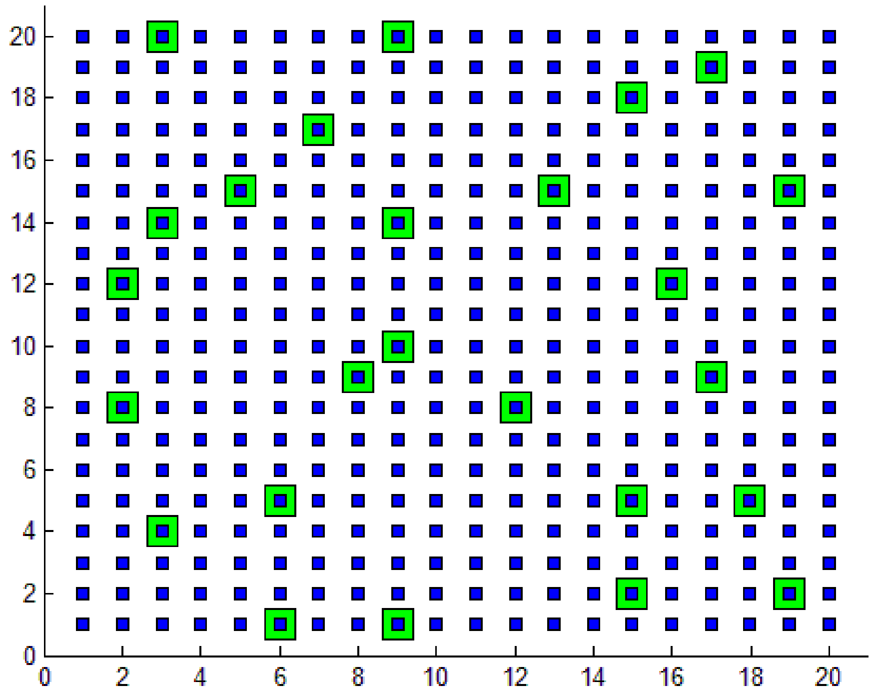


Fig 5.2 – Stage 2

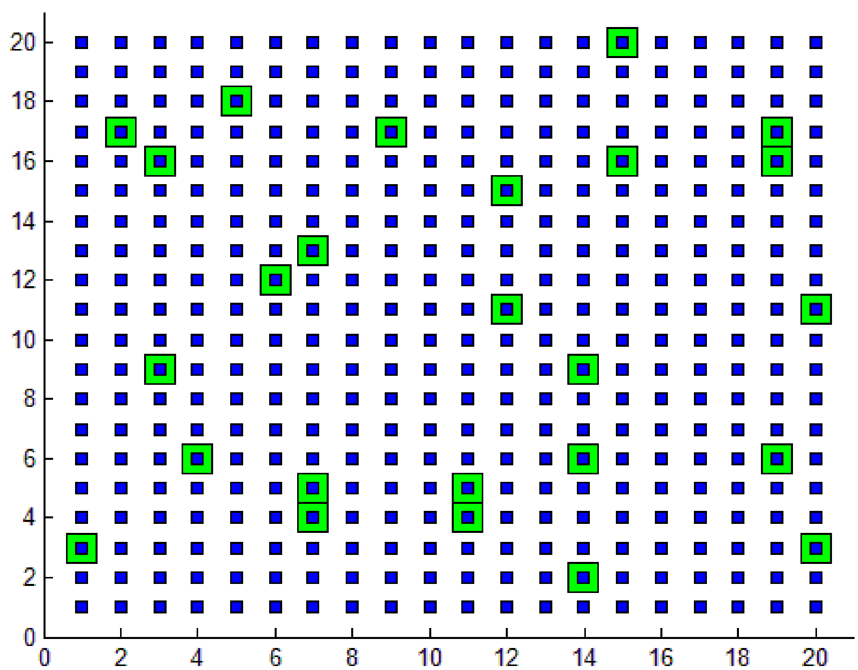


Fig 5.3 – Stage 3

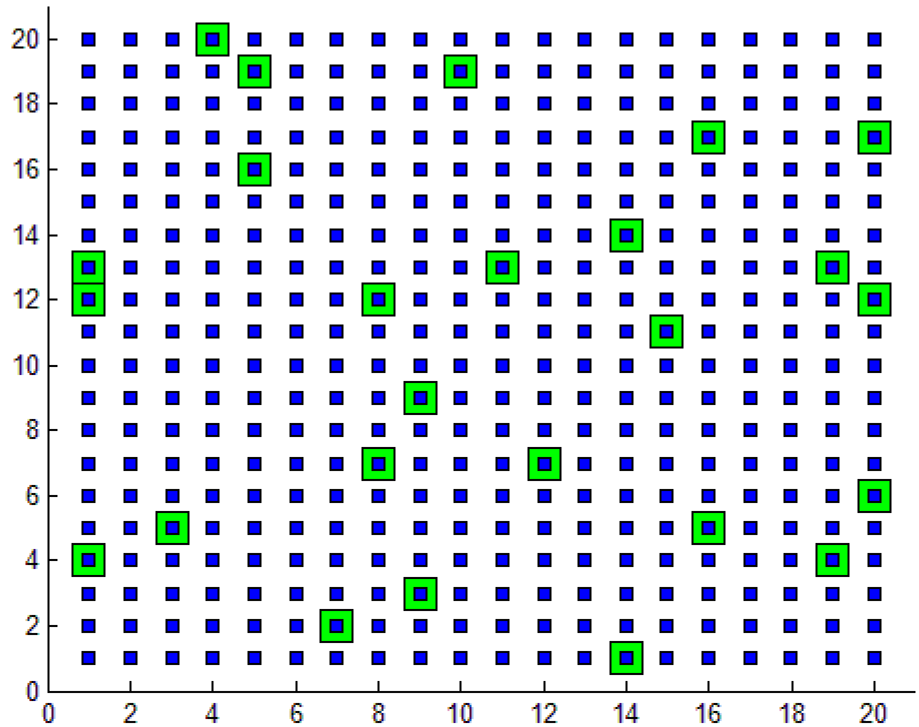


Fig 5.4 – Stage 4

In each of these figures, the smaller dots indicate the sensor nodes. The larger dots indicate CHs. The node in each sector having the highest residual energy is selected as the head.

5.2 Simulation results for Dijkstra's Algorithm:

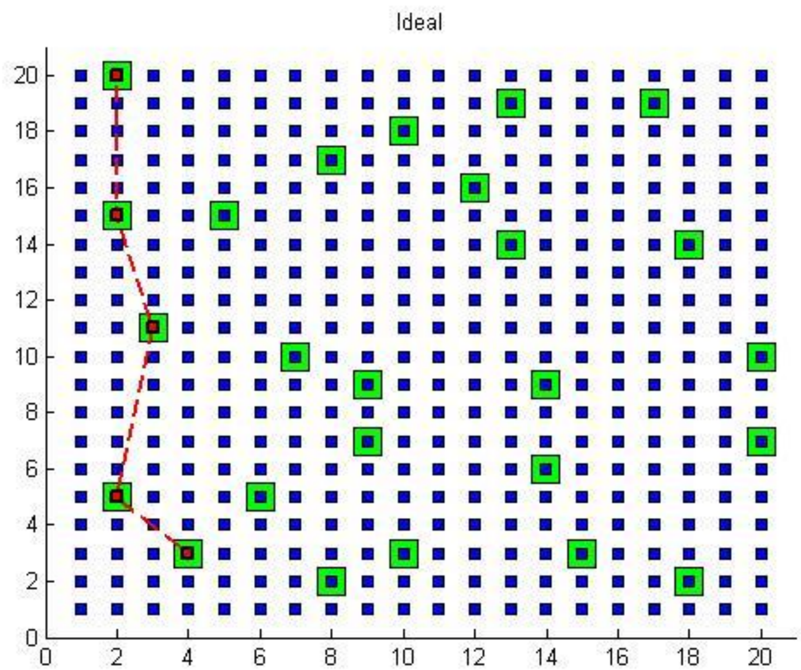


Fig 5.5

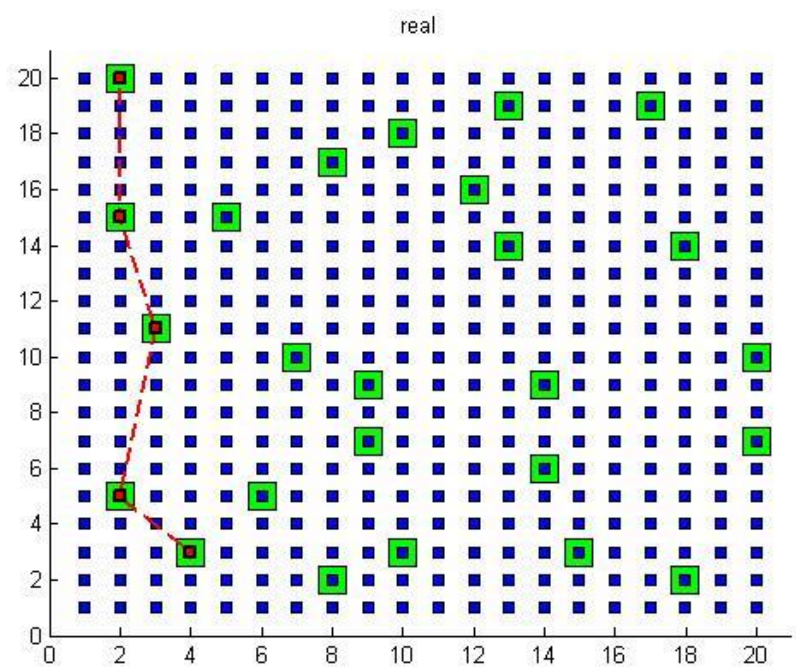


Fig 5.6

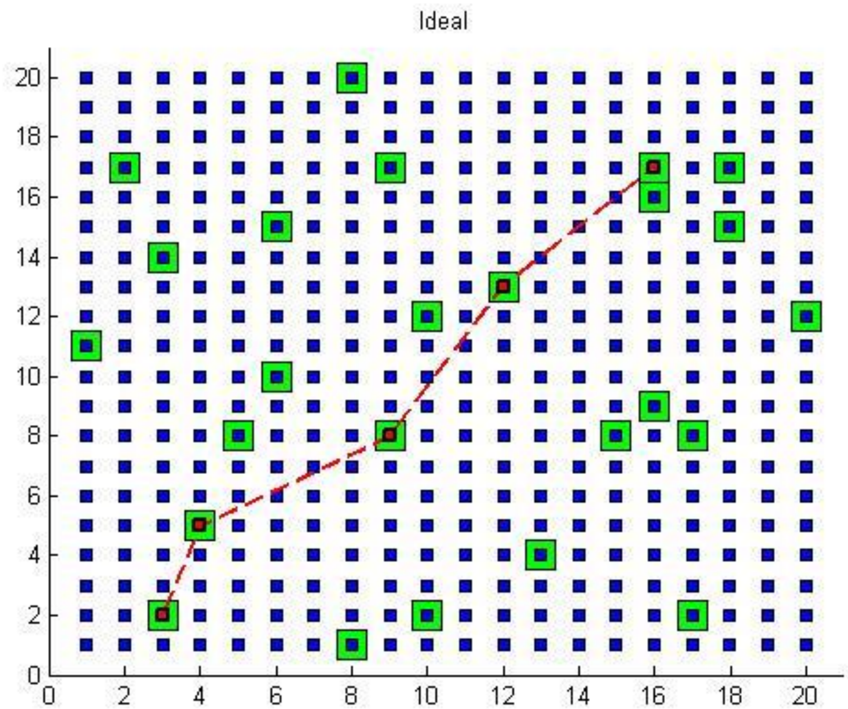

Ideal
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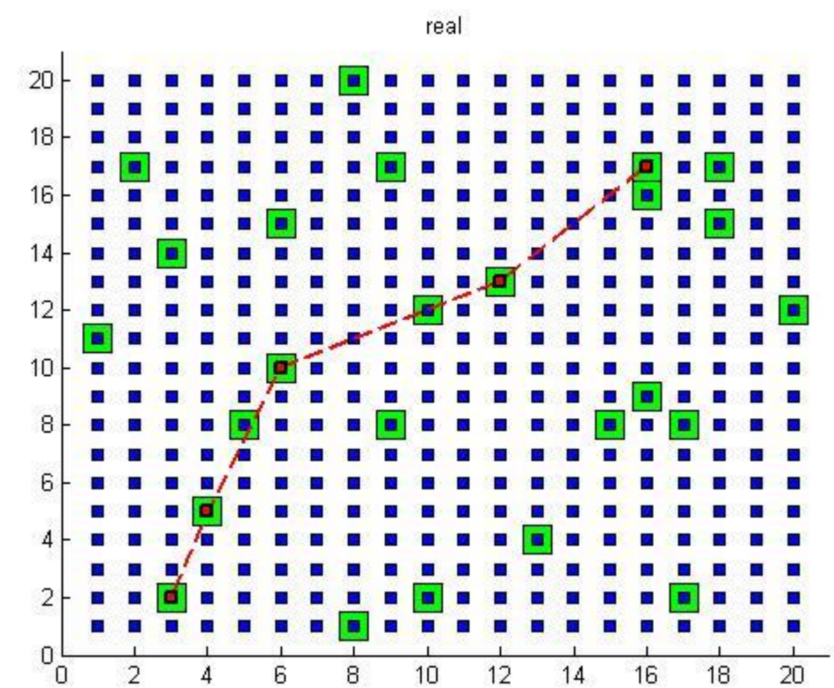
Fig 5.7


real
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18
20

Fig 5.8

In the above shown figures the dotted lines indicate the data path. The figures titled "Ideal" show the data path if dynamic routing were possible in case of WSNs. The figures titled "Real" show data path programmed into sensor nodes using the reference distribution.

5.2Simulation results for MVEE:

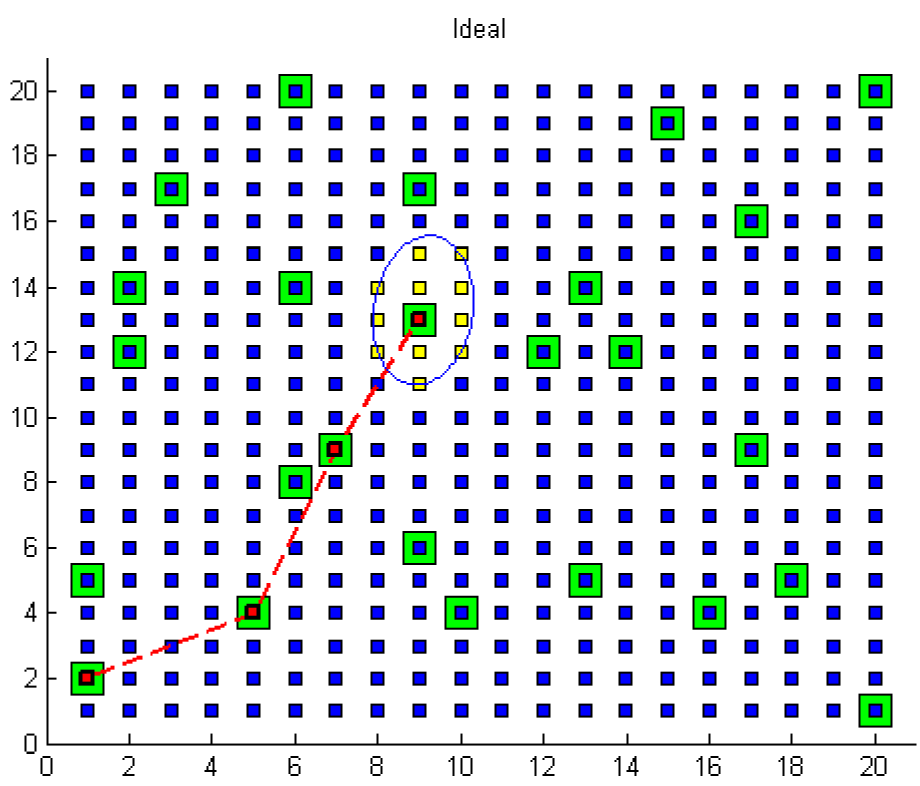

Fig 5.9 – stage 1 (ideal)

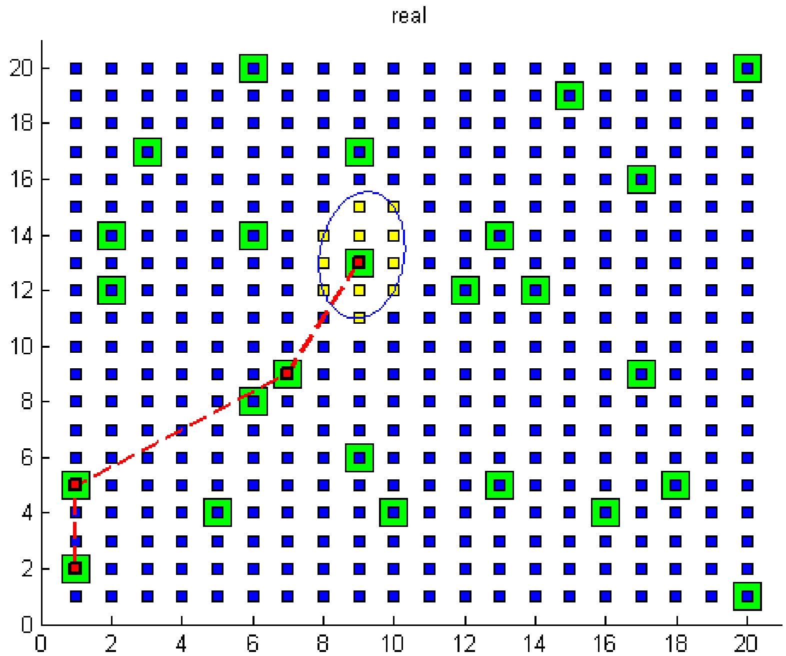

Fig 5.10 – stage 1 (real)

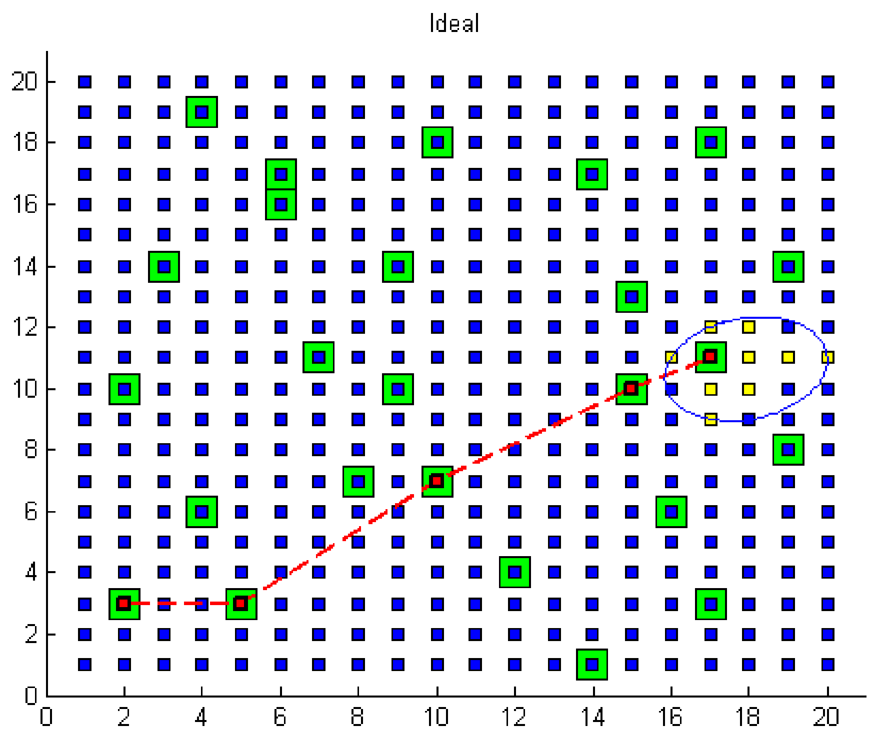

Fig 5.11 – stage 2 (ideal)

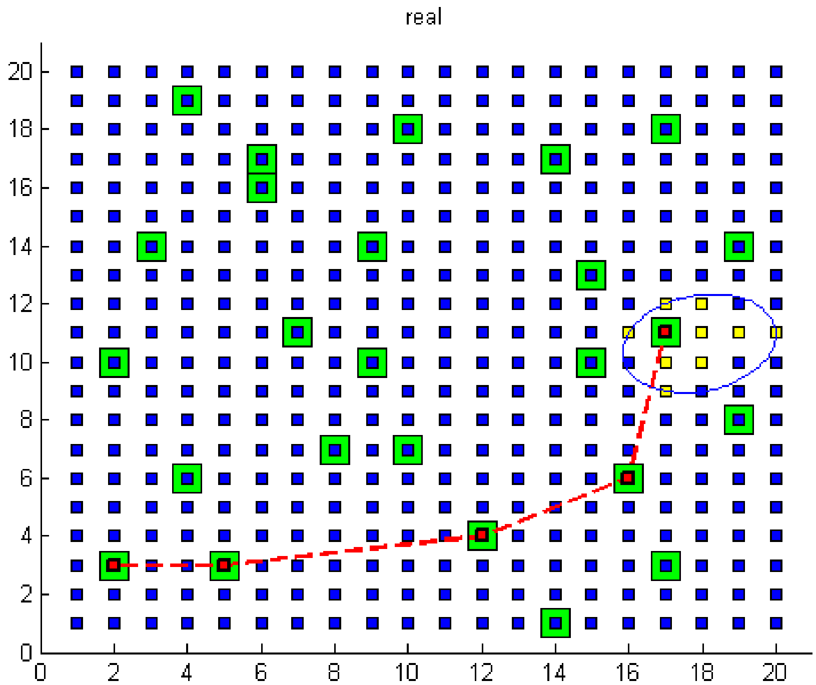

Fig 5.12 – stage 2 (real)

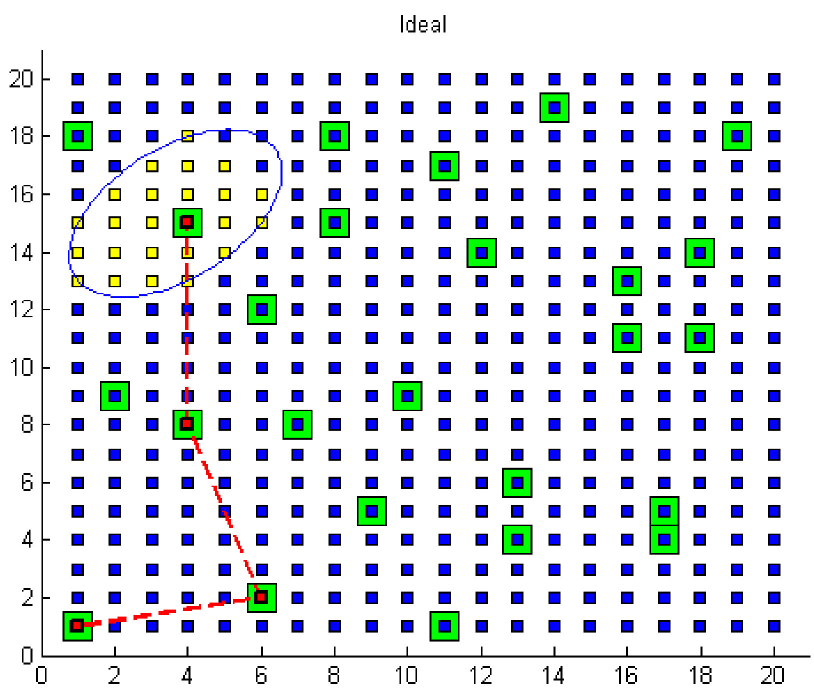

Fig 5.13 – stage 3 (ideal)

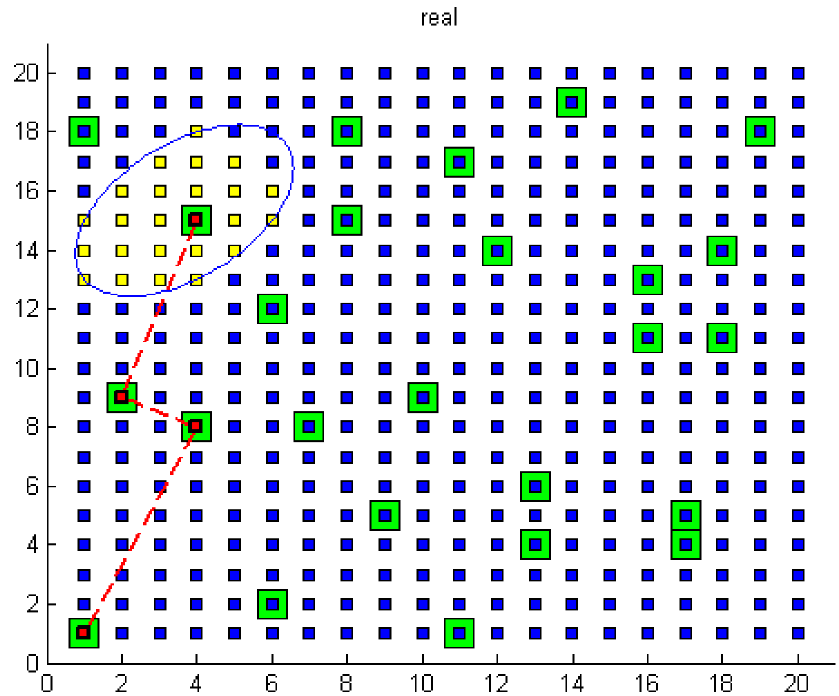

Fig 5.14 – stage 3 (real)

In the above shown figures, the lighter nodes are the nodes reporting an anomaly. The ellipse shown is the minimum volume ellipsoid calculated. The figures titled “Ideal” are for the case if dynamic path calculation were possible for WSNs. The figures titled “REAL” show the actual data path programmed into the sensor nodes.

Chapter-6
CONCLUSION

6.1 Conclusion:

This thesis proposes a novel method for environment monitoring using clustering and minimum volume ellipsoid method. It includes study of clustering, cluster head selection, data routing and data representation, all done to improve network lifetime. Energy efficient clustering was used for cluster head selection which showed much improvement in network lifetime than other algorithms.

Data routing was done via multi-hop communication to decrease transmission distance. The data path was found out by applying a modified version of Dijkstra's algorithm to a reference distribution which tries to reduce the number of hops and at the same time tries to keep transmission distance a low as possible. And finally minimum volume enclosing ellipsoid was used as data representation technique. It reduces the huge bulk of data to a few parameters which indicate the affected area thus reducing the transmission load by finding out the ellipse that passes through the outermost points in the required area.

6.2 Scope for Future Work:

Throughout the thesis reduction of transmission load has been the point of concern. Development of proper communication protocols may reduce the power consumption even more increasing the network lifetime. Suitable communication protocol will compound the effect of energy efficient clustering and data transmission by having less overhead. Also fuzzy techniques may be applied for cluster head selection to make it more distributed and balance the network load.

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